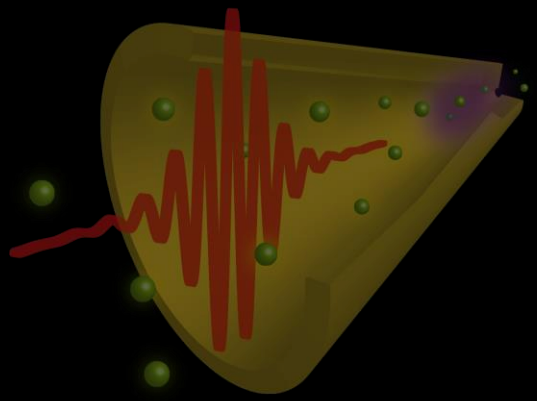
Enhancement of Extreme-Ultraviolet Fluorescence

Murat Sivis

University of Göttingen

4th Physical Institute – Solids and Nanostructures



2016 International Workshop

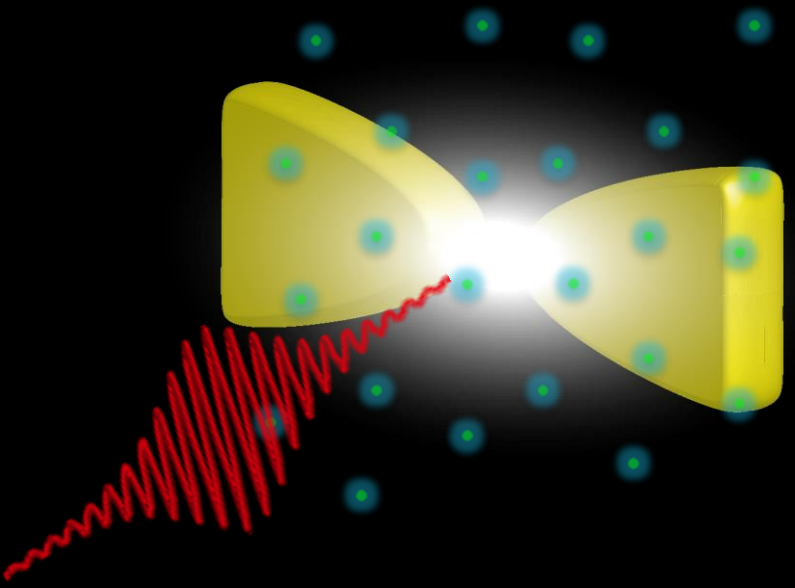
on EUV and Soft X-Ray Sources

-

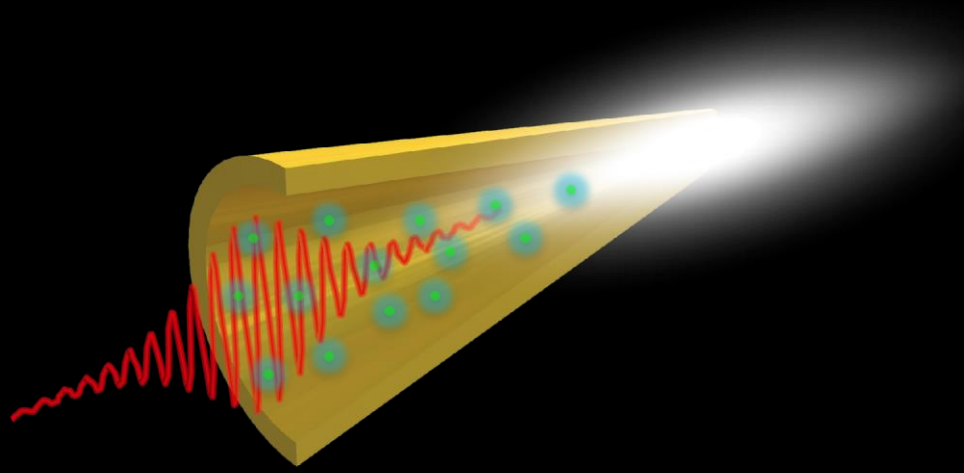
November 2016 in Amsterdam

Nonlinear gas excitation in nanostructures

Resonant nanoantennas



Hollow waveguides

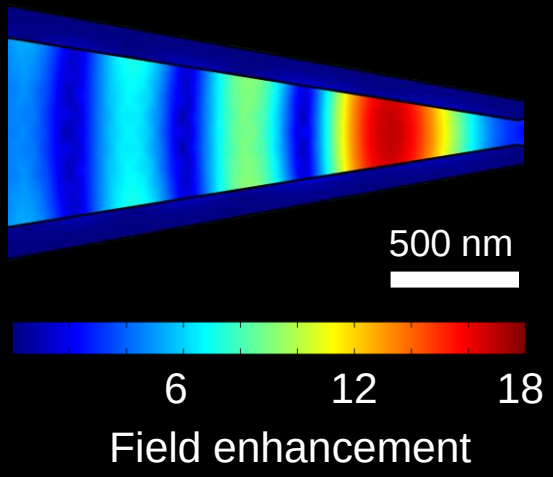


nJ pulses
@ 80 MHz

Frequency domain
Simulations

- 10 TW/cm²

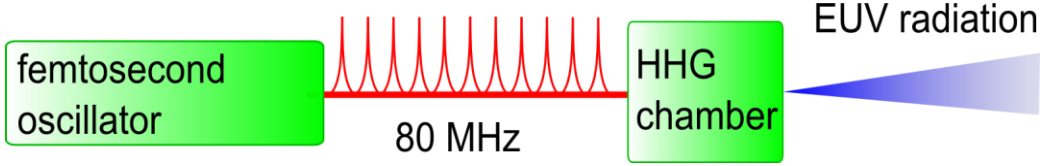
Local intensities possible

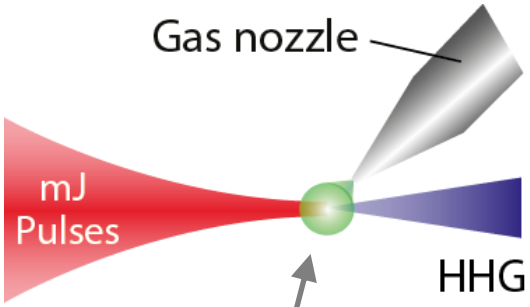


HHG with plasmoic nanostructures

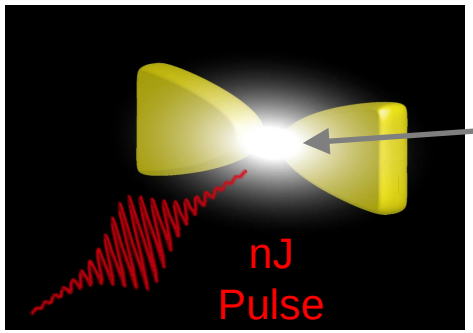
State-of-the-art HHG:

nanostructure-enhanced HHG:



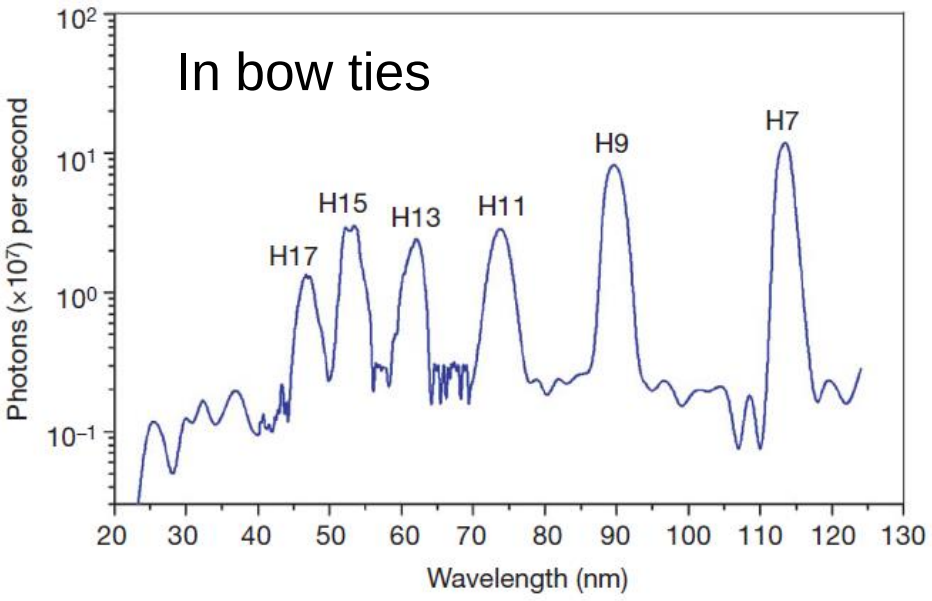


- Compact, cheap
- Higher generation rate
- Control over HHG



$I_{local} > 10\ TW/cm^2$

Plasmonic High Harmonic Generation?



Kim *et al.*, Nature **453**, 757 (2008)

NATURE|Vol 453|5 June 2008 NEWS & VIEWS

ATTOSECOND PHYSICS

An easier route to high harmony

Mark I. Stockman

The generation of ultrashort light pulses by atomic ionization and recombination doesn't come cheap. But by niftily exploiting the play of light on a nanostructured surface, it can be done on a table-top.

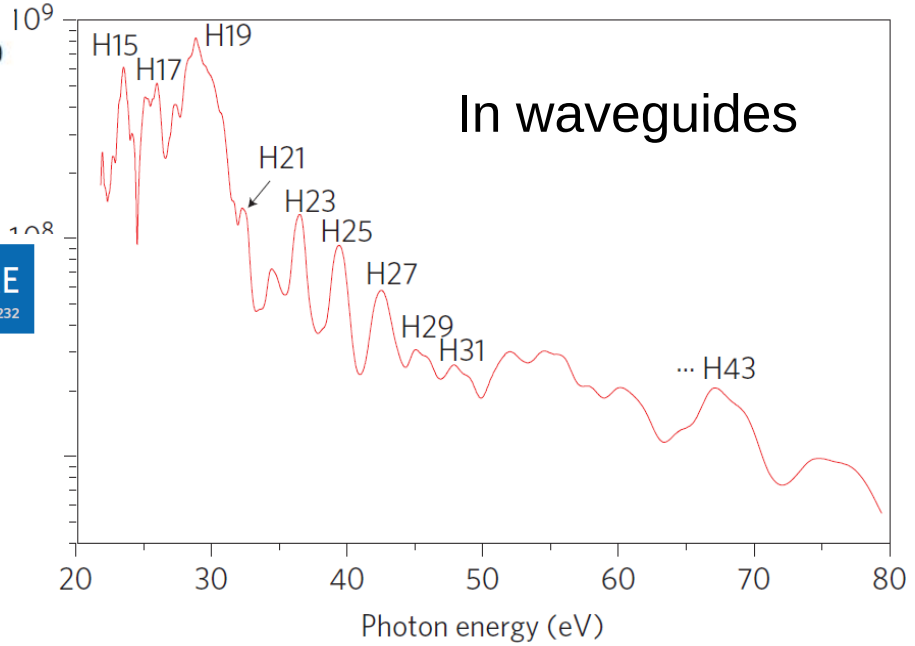
microRNAs (miRNAs) — which are distinct in their biogenesis and cellular roles (Box 1). The studies[1–6] find that endo-siRNAs regulate transposons as piRNAs do; that, like miRNAs, they can arise from hairpins; and that, in flies, their processing involves a similar co-factor to the processing of miRNAs (Box 1).

This blurring of boundaries among different types of small RNA, together with the newly established links between siRNAs and pseudogenes, has interesting evolutionary implications. In plants, inverted duplications containing a protein-coding gene have been proposed[16] as a mechanism to create new

Extreme ultraviolet (EUV) radiation has great potential to be extreme not just in name, but in usefulness. It is the band of ultravi

The secret of the authors' success is the

with the shortest



nature photonics
REVIEW ARTICLE
PUBLISHED ONLINE: 24 DECEMBER 2013 | DOI: 10.1038/NPHOTON.2013.232

Nanofocusing of electromagnetic radiation

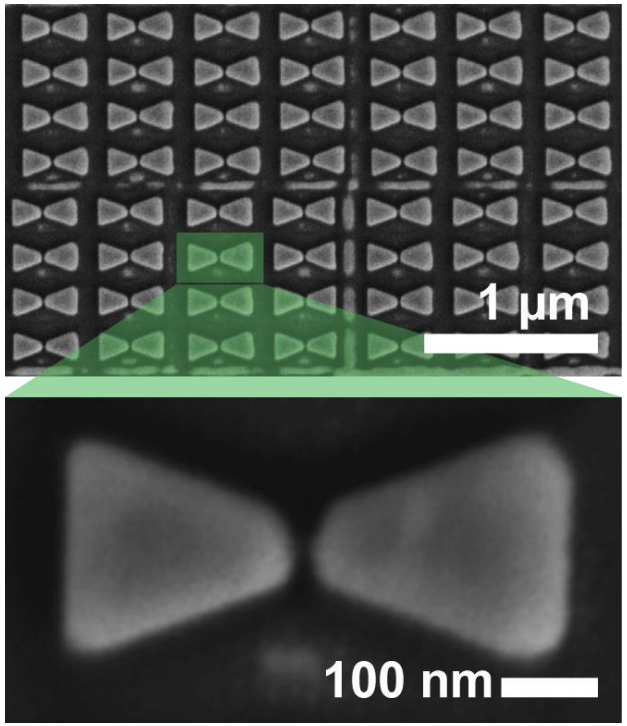
Dmitri K. Gramotnev[1]* and Sergey I. Bozhevolnyi[2]

of ultrashort extreme-ultraviolet pulses with a high spatiotemporal coherence constitutes one of the most exciting nanofocusing applications, offering a way to bring high-spatial-resolution imaging techniques into the domain of attosecond science.

Park *et al.*, Nature Photon. **5**, 677 (2011)

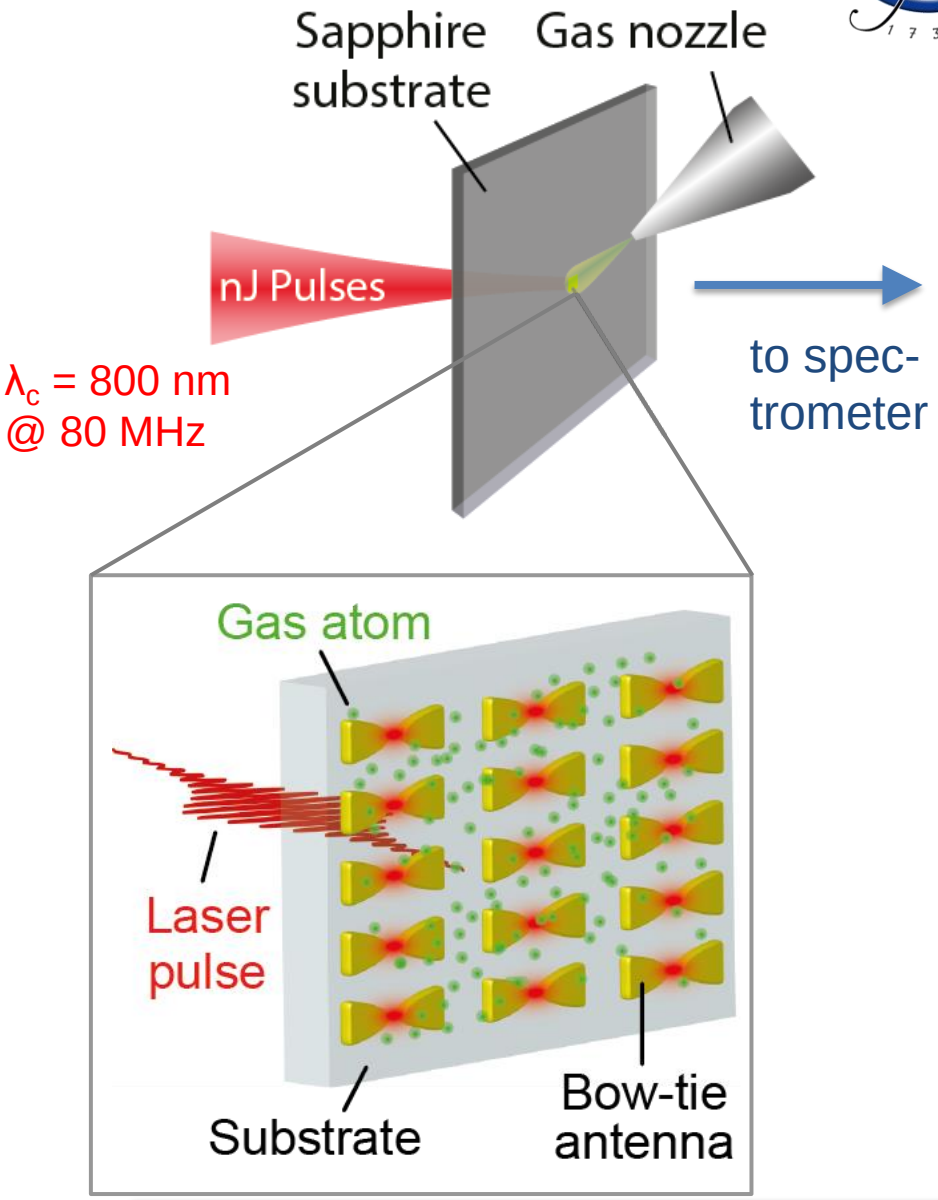
Experiment

Gold bow-tie nanoantennas

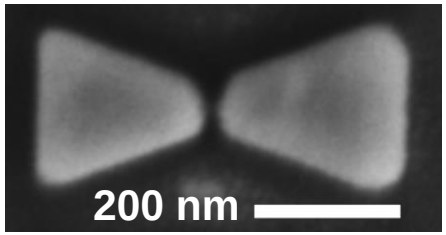


Scanning electron micrographs

- 100 nm gold film on sapphire
- Focused ion beam lithography
- High structure quality



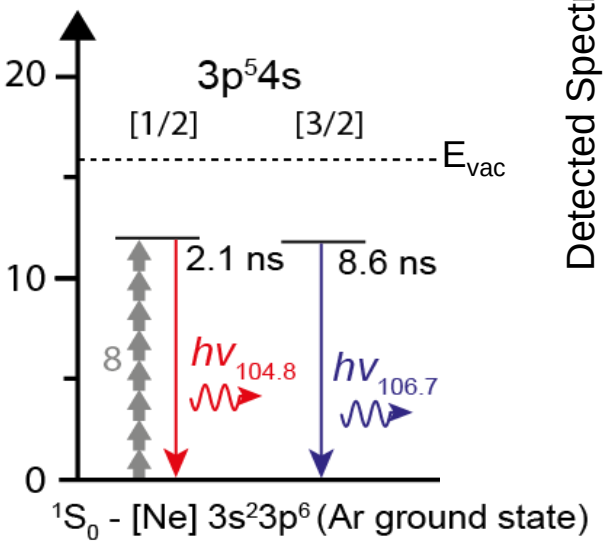
Nanostructure-enhanced ~~HHG~~ ? Fluorescence !



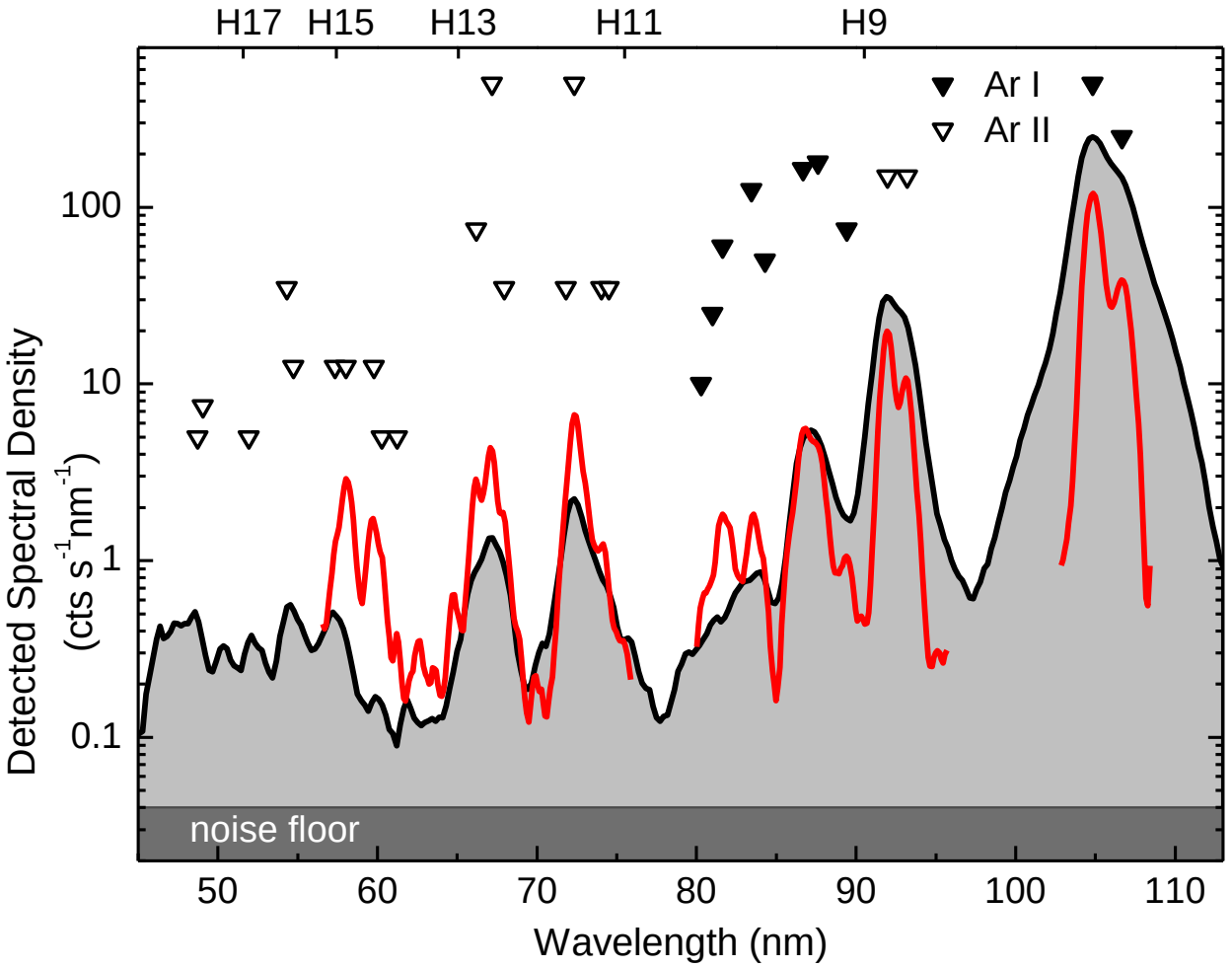
Peak intensity:

0.15 TW/cm²

Gas: argon

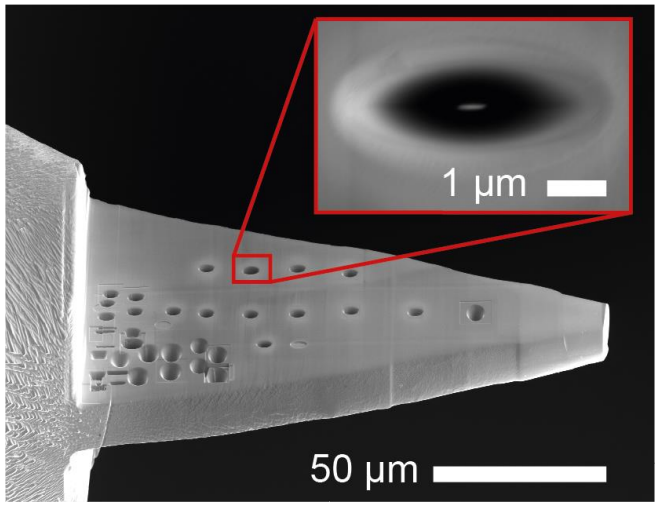


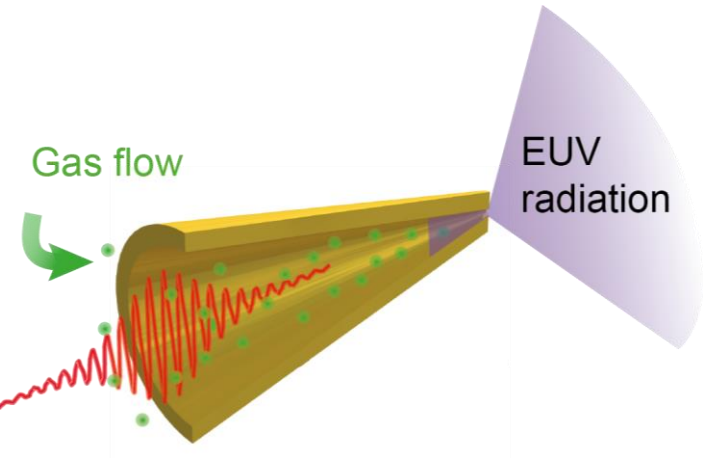
Incoherent Fluorescence instead of HHG

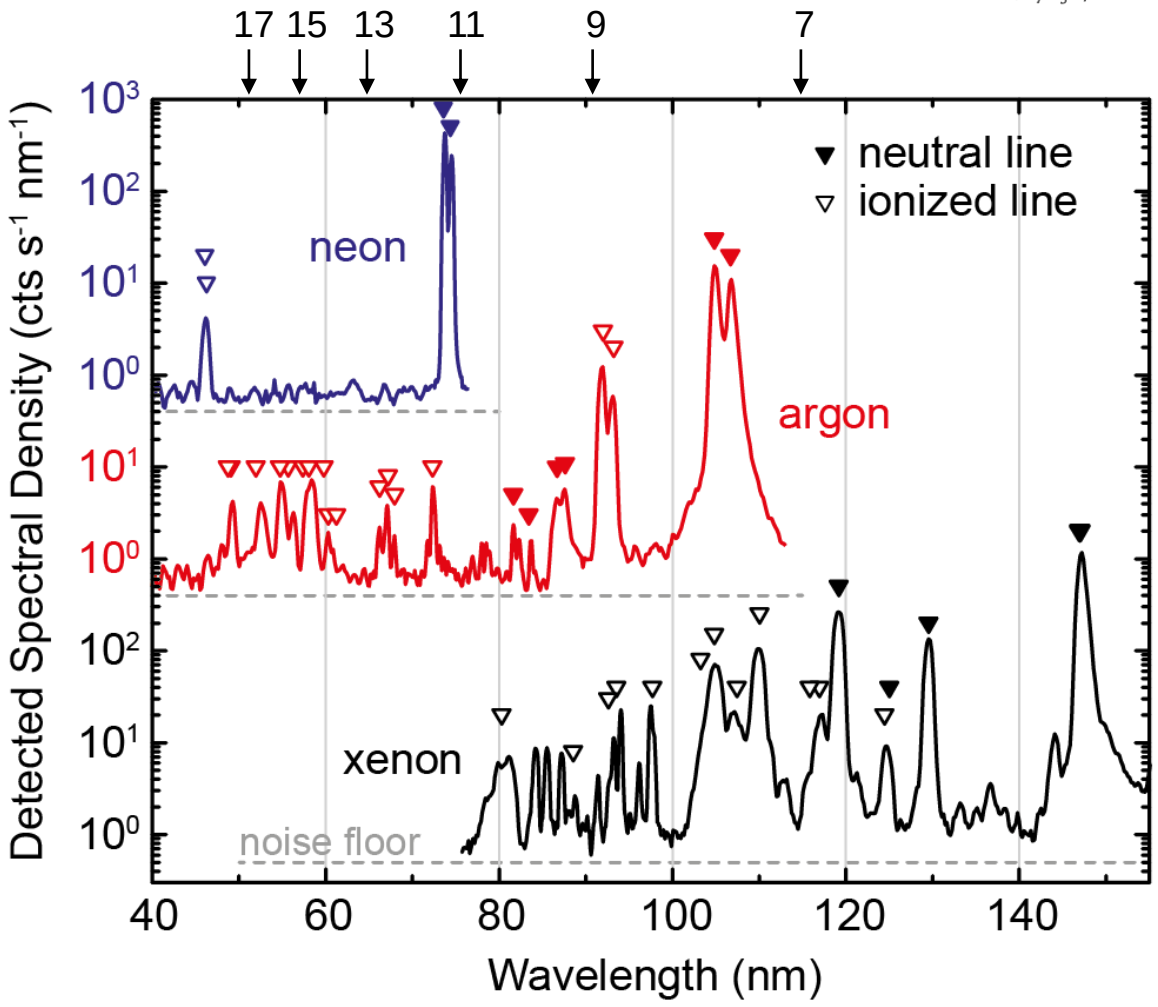


Sivis *et al.*, Nature **485**, E1 (2012)

EUV light generation in hollow waveguides



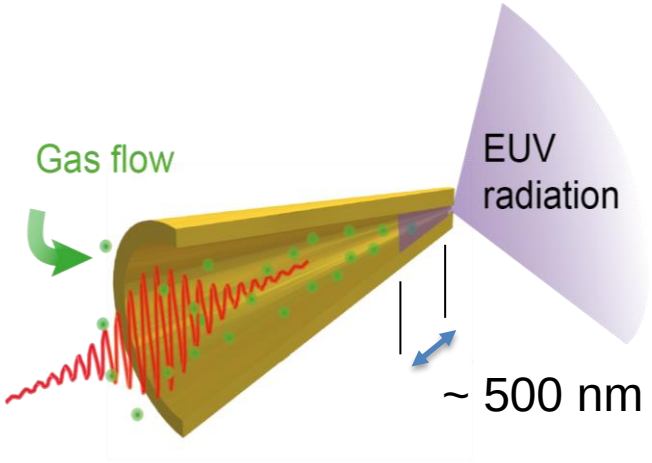




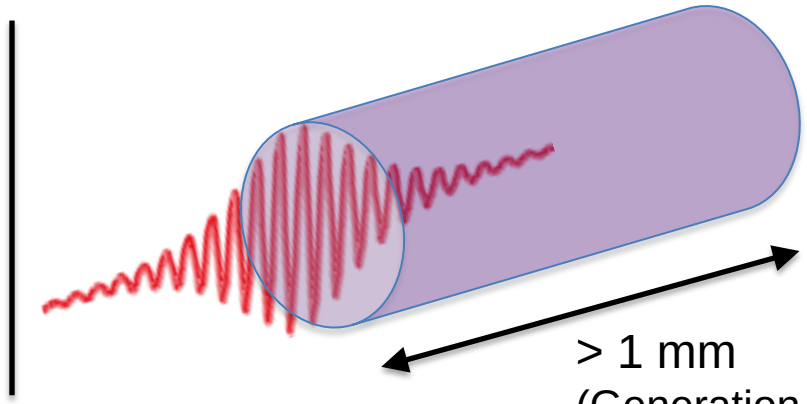
Sivis *et al.*, Phys. Rev. Lett. **111**, 085001 (2013)

Conversion efficiency of nano-HHG

Nanostructure-enhanced HHG



HHG with amplified pulses



HHG power scales quadratically with pressure-length product *p*L:

$$P_{HHG} \propto f_{rep}\,(pL)^2 A$$

$$\left(\frac{L_{nano}}{L_{conv}}\right)^2 \approx 10^{-7}$$

$$\frac{A_{nano}}{A_{conv}} \approx 10^{-4}$$

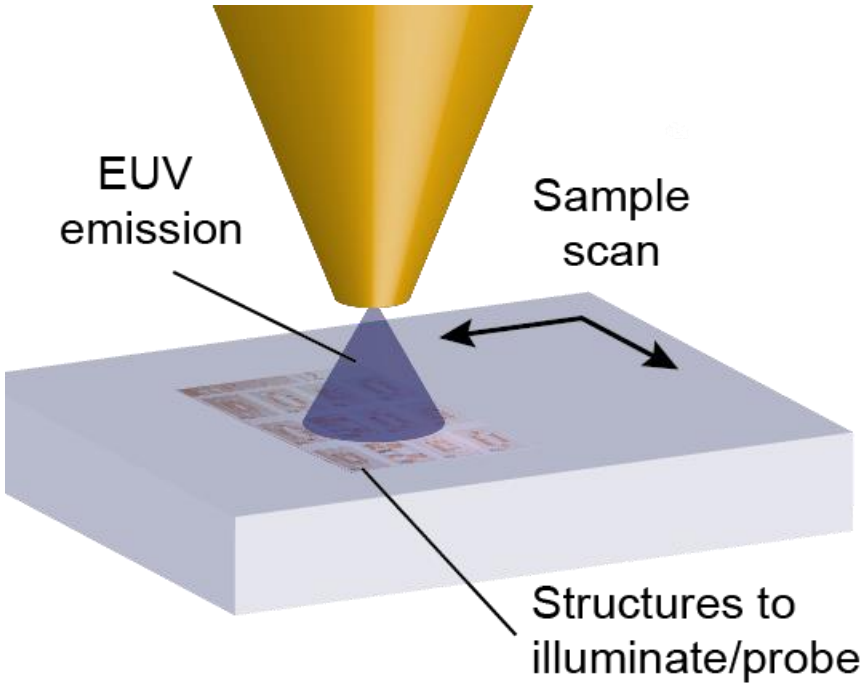
No efficient HHG in localized fields

Fluorescence power linear in *p*L

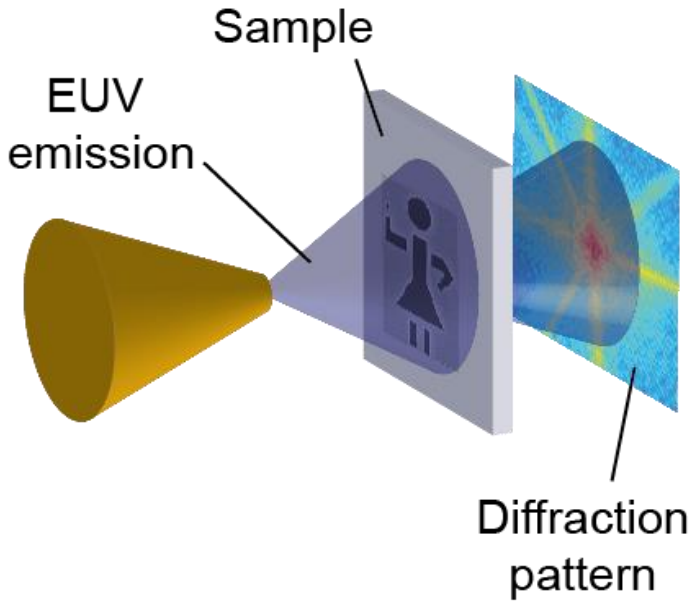
$$P_{ALE} \propto f_{rep}\, pL\, A$$

Han S. *et al*. *Nat. Comm.* **7** (2016).

Possible applications for the EUV fluorescence from waveguides (10^{10} Photons/s)



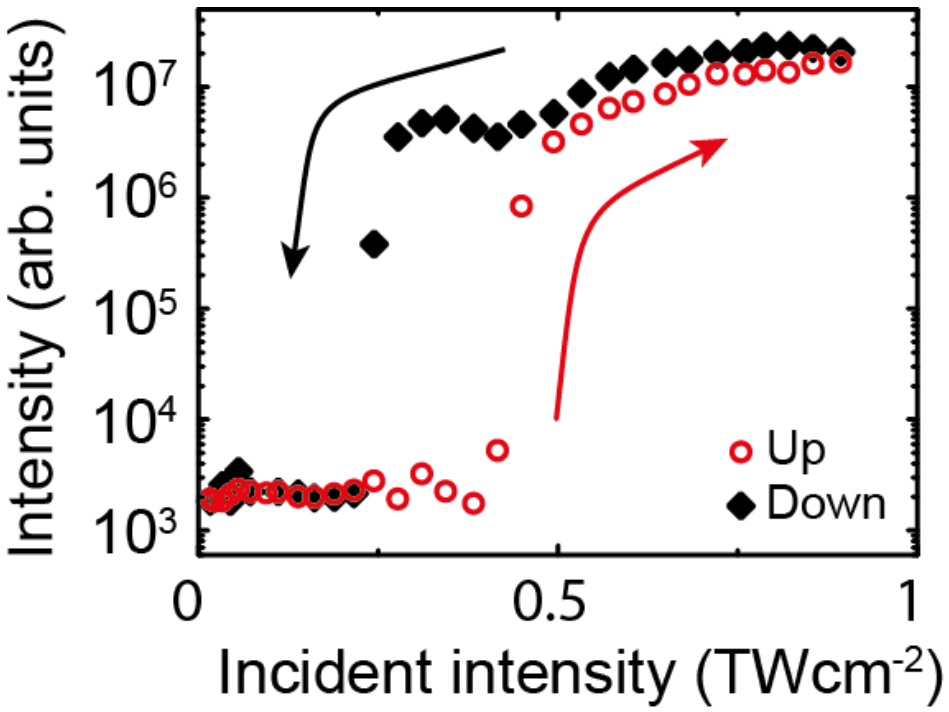
Near-field scanning optical microscopy (NSOM) and lithography

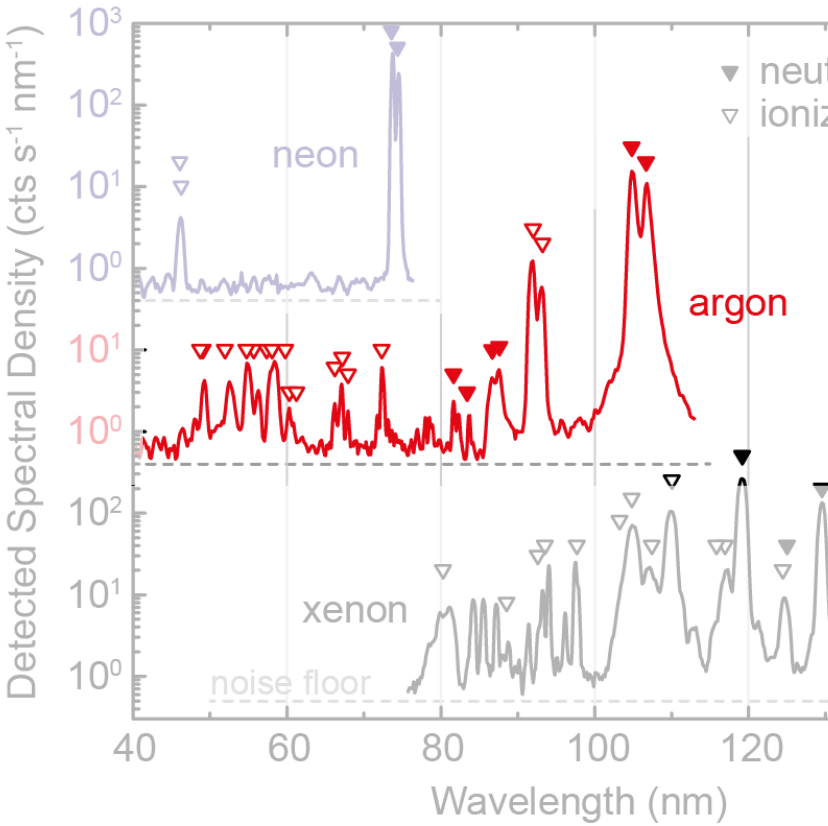


Coherent diffractive imaging (CDI)

Formation of a bistable nanoplasma

- Ignition behavior
- Pronounced intensity hysteresis

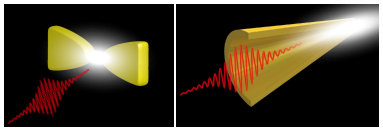


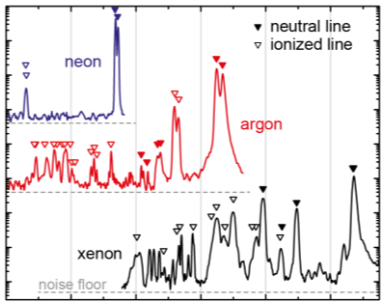


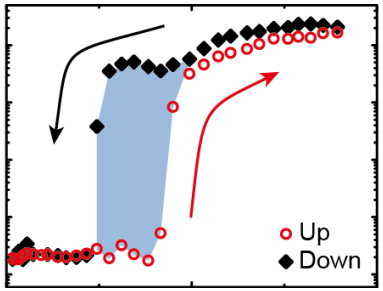
Sivis *et al.*, Phys. Rev. Lett. **111**, 085001 (2013)

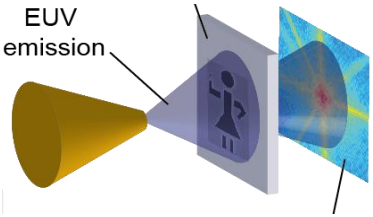
Conclusion

- ✓ Highly nonlinear effects are feasible in nanostructure-enhanced fields (EUV Fluorescence)
- ✓ Coherent processes (HHG) exceedingly inefficient
- ✓ Further nonlinear EUV effects:
  - ➢ Low-order harmonic generation
  - ➢ Gauging of plasmonic fields
  - ➢ Bistable nanoplasma









Courant Research Centre
Nano-Spectroscopy and X-Ray Imaging

Founded by DFG SFB 755